Original Article

Iron and zinc retention in common beans (*Phaseolus vulgaris* L.) after home cooking

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Abstract

Background: According to the World Health Organization (WHO), iron, iodine, and Vitamin A deficiencies are the most common forms of malnutrition, leading to severe public health consequences. The importance of iron and zinc in human nutrition and the number of children found to be deficient in these nutrients make further studies on retention in cooked grains and cooked bean broth important.

Objectives: This work aimed to evaluate iron and zinc retention in six common bean (*Phaseolus vulgaris* L.) cultivars under the following conditions: raw beans, regular pot cooking, pressure cooking, with and without previous water soaking, and broth.

Design: Determination of iron and zinc content in the raw, cooked bean grains and broth samples was carried out by Inductively Coupled Plasma (ICP) Optical Emission Spectrometry (Spectro Analytical Instrument – Spectroflame P). All experiments and analyses were carried out in triplicate.

Results: Overall, regardless of the cooking method, with or without previous water soaking, the highest zinc concentration was found in the cooked bean grains. However, pressure cooking and previous water soaking diminished iron retention in the cooked grains, while increasing it in the bean broth.

Conclusion: The common bean was confirmed to be an excellent source of iron and zinc for human consumption, and it was suggested that beans should be consumed in a combined form, i.e. grain with bean broth.

Keywords: *leguminosae*; *mineral deficiencies*; *cooking methods*; *micronutrients*; *food analysis*; *food composition*; *common beans*

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According to the World Health Organization (WHO), iron, iodine, and Vitamin A deficiencies are the most common forms of malnutrition, leading to severe public health consequences. Iron and zinc deficiencies can cause anemia, compromising physical work capacity, and leading to growth retardation and alterations in neurological function and immunological response (1–4). Such deficiencies are in general caused by the lack of financial means to acquire and consume red meat, chicken, fish, fruit, and vegetables in the amounts required (5, 6).

Leguminous grains play an important role in human nutrition, being one of the main foods in the standard diet of low-income people in developing countries. The common bean (*Phaseolus vulgaris* L.) contains essential minerals, such as iron, zinc, calcium, and phosphorus. Normally, its iron and zinc contents range from 18.8–82.4 mg of Fe/g and from 32.6 to 70.2 mg of Zn/kg (7, 8).

However, these levels may vary in function depending on various factors: species; variety; processing factors, such as storage time, temperature, and food preparation (9).

Several types of bean grains are commercialized in the Brazilian market, with 'carioca' (red beans) being currently the most consumed. However, the small and opaque bean seeds (black beans) are more popular in southern and eastern Paraná, Rio de Janeiro, southeastern Minas Gerais, and southern Espírito Santo.

The majority of the adult population consumes cooked bean grains combined with bean broth. In Brazil, the broth is consumed as an appetizer drink. However, studies on standard food consumption of infants (0–5 years old) – one of the main groups presenting with risk of nutritional deficiencies – have revealed that infants are fed exclusively bean broth diet. Current dietary recommendations for children weaned are important because this is the period in which eating habits are established and continue into adolescence and adulthood (10–12).

In view of the high bean consumption in Brazil and in other developed and developing countries, the importance of iron and zinc in human nutrition, and the number of children deficient in these nutrients, further studies must be carried out on retention of these minerals in the cooked grains and cooked bean broth.

This work aimed to evaluate iron and zinc retention in six common bean cultivars (*Phaseolus vulgaris* L.) under the following conditions: raw beans, regular pot cooking, pressure cooking, with and without previous water soaking, and broth.

Materials and methods

Raw material

Six common bean (*Phaseolus vulgaris* L.) cultivars samples, BRS Pontal (beige); BRS Grafite (black); BRS Marfim (brown); Jalo Precoce (beige); BRS Radiante (beige), and BRS Vereda (beige), were cultivated and provided by Embrapa Rice and Beans, Santo Antônio de Goiás, GO.

Home cooking methods

The grains of six common bean cultivars were submitted to four different cooking methods (Fig. 1): (1) regular pot cooking without previous soaking (WPSCP); (2) regular pot cooking with previous water soaking (SCP); (3) pressure cooking without previous water soaking (WSPP); and (4) pressure cooking with previous water soaking (SPP) during previously determined cooking times using the Burr Experimental Cooker. The cooking time method determination was done according to the same methodology adopted by Burr and Morris (1968), the time was determined by an experimental laboratory cooker (JAB-77) 'minor type' with 25 pin, weighing 90 g each, manufactured in Jaboticabal – SP. The cooking time was determined after the 13th pin fell down.

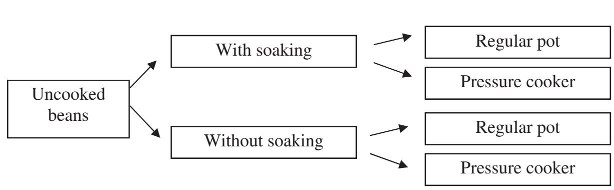

Fig. 1. Common bean home cooking methods used.

Sample size was 100 g of beans cooked in 1,000 ml water (1:10). All experiments were carried out in triplicate.

Previous bean soaking in water was performed over 16 h (overnight) in a glass beaker at room temperature. The grains were cooked in the deionized soaking water.

The pots and lids were washed in water, immersed in a 5% nitric acid solution over 1 h, and rinsed with ultra-pure water (Mili-Q, Millipore, Milford, USA) before being submitted to the different cooking methods.

Regular pot cooking was carried out with the lid half open; 500 ml of water was added during cooking to correct the loss of water by evaporation during cooking. No water replacement was necessary in pressure cooking.

Preparation of the samples for iron and zinc analysis

All the material was previously decontaminated in a nitric acid solution ($HN0_3$ – 1:1), prepared with distilled water. The raw bean samples were selected manually before being polished with flannel cloth for 5 min and kept in clean glass receptacles.

The polished bean grains were washed with deionized water (Mili-Q, Millipore, Milford, USA) and hand crushed. After washing, all the water was discarded. Grain drying was performed in an oven at 60 °C, with no air circulation, overnight.

The raw grains of each cultivar were grounded in a zirconium ball mill (RETSCH model MM200, Retsch Gmbtt & Co. KG. Haan, Germany), until a sufficient amount was obtained for analysis.

The grounded raw bean samples were divided into three aliquots of 0.2 g and placed in assay tubes.

The broth in the cooked bean samples was completely drained through a plastic sieve into a beaker (previously weighed), and the bean grains were transferred into another glass receptacle, with three aliquots of 0.8 g of cooked grains and 2.0 g of broth being transferred into assay tubes.

Sample digestion was carried out by acid hydrolysis, through the addition of 2 ml of a nitric perchloric acid solution (2:1) for approximately 16 h at room temperature. After oxidation, the samples were heated in a digestion block (Technal, São Paulo, Brazil), in a fume hood at a slow boil to 100 °C (±2 °C) over 1 h and maintained for an additional 2 h at 170 °C (±2 °C). After the samples were cooled at room temperature, 2 ml of the nitric perchloric solution were added to each tube, which were returned to the digestion block for another 4 h at 170 °C (±2 °C) (13, 14).

The tubes were removed from the digestion block and the samples were transferred into a volumetric flask (25 ml) and the volume completed with ultra-pure water (Milli-Q, Millipore, Milford, USA).

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Iron and zinc analysis

Determination of iron and zinc content in the raw, cooked bean grains and broth samples was carried out by Inductively Coupled Plasma (ICP) Optical Emission Spectrometry (Spectro Analytical Instrument – Spectroflame P). Micronutrient concentrations were calculated based on calibration curves with iron and zinc standard solutions (0.25, 0.5, 1.0, and 1.5 mg/kg) (14). All analyses were carried out in triplicate and the results were thus calculated:

$$(\text{ICP mineral emission}) \times (\text{dilution factor})/(\text{aliquot weight}) = (\text{sample mineral content} - \text{mg/kg})$$

$$(\text{sample mineral content} - \text{mg/kg})/10 = (\text{sample mineral content} - \text{mg/100 g})$$

$$(\text{sample mineral content} - \text{mg/100 g}) \times 100/(\text{sample dry weight}) = (\text{mineral dry basis content} - \text{mg/100 g})$$

Moisture analysis

Determination of bean grain moisture was carried out by the gravimetric method according to a methodology developed by the Instituto Adolfo Lutz (15).

Statistical analysis

The statistical analyses were carried out using the GraphPad Prism Software Version 4. Descriptive methods and t test analysis were applied. Descriptive analysis was used to characterize the samples studied. For each mineral, differences between the bean broth and bean grain results in the samples, with and without previous water soaking, were evaluated by the paired t test. The differences between the bean broth and bean grain in the pressure cooker and regular pot samples were evaluated by the non-paired t test.

Results

The cooking times of common bean cultivars using the Burr cooker, with and without previous soaking in water, is shown in Table 1.

The Jalo Precoce variety needed the highest cooking time (without previous soaking in water) and the BRS Pontal the lowest. However, when cooked after soaking, the BRS Radiante had the highest cooking time and the BRS Grafite the lowest one.

Table 2 shows the iron and zinc contents in the raw bean grains. The cultivar BRS Marfim had the highest iron content (74.7 mg/kg) followed by the cultivars BRS Grafite (69.5 mg/kg) and BRS Vereda (68.8 mg/kg).

The cultivars analyzed presented zinc contents ranging from 33.8 mg/kg (Jalo Precoce) to 43.1 mg/kg (BRS Grafite).

Table 1. Cooking times of common bean cultivars using the Burr cooker, with and without previous soaking in water

	Cooking time (min)	
Cultivar	Without soaking	With soaking
BRS Vereda	52.18^{ab}	14.31^{bc}
BRS Grafite	49.98^{ab}	13.81^{bc}
BRS Radiante	59.18^{ab}	19.75^{a}
BRS Pontal	46.95^{b}	15.08^{bc}
BRS Marfim	53.37^{ab}	14.33^{bc}
Jalo Precoce	67.50^{a}	16.55^{b}

Different letters in the same column differ significantly at 5% probability.

The highest iron content was found in BRS Pontal (54.9 mg/kg) in the beans pressure-cooked with previous soaking and without soaking in the BRS Vereda cultivar (56.8 mg/kg). Considering the contents of the broth, the total iron contents in both were 62.3 and 70.0 mg/kg, respectively (Table 3).

The iron contents in the beans cooked with and without previous soaking in a regular pot were highest in the BRS Marfim cultivar, 74.4 and 70.4 mg/kg, respectively. The total iron contents for both cooking methods using a regular pot, considering the content in the broth, were 75.3 (BRS Marfim) and 74.8 mg/kg, respectively.

A significant difference was found in the iron contents, both in the cooked bean grains and bean broth, with and without previous water soaking and pressure-cooked, compared to those cooked in a regular pot. In addition, the iron content in the bean grains previously soaked in water and in those without water soaking was significantly different (Table 3).

The zinc contents were highest in the BRS Grafite (36.1 and 38.8 mg/kg) cooked under pressure with and without previous soaking (Table 4). The total zinc contents in both pressure cooking methods, considering the content in the broth, were 43.0 and 43.1 mg/kg, respectively, in the BRS Grafite cultivar.

The zinc contents were 36.2 mg/kg (BRS Pontal) and 38.5 mg/kg after being cooked in a regular pot, with and without soaking, respectively. Considering the beans

Table 2. Iron and zinc content (mg/kg dry matter) in raw beans[1]

Cultivars	Fe (mg/kg)[2]	Zn (mg/kg)[2]
BRS Vereda	68.8 (±0.30)	39.4 (±0.40)
BRS Grafite	69.5 (±0.39)	43.1 (±0.25)
BRS Radiante	53.1 (±1.08)	33.5 (±0.48)
BRS Pontal	62.3 (±1.91)	42.7 (±0.66)
BRS Marfim	74.7 (±0.95)	39.1 (±1.01)
Jalo Precoce	55.8 (±0.60)	33.8 (±0.53)

Mean and standard deviation; 1, Dried overnight; 2, Dry basis.

Table 3. Iron content (mg/kg dry matter) in home cooked beans and bean broth

	Pressure cooking				Regular pot			
	With soaking (SPP)		Without soaking (WSPP)		With soaking (SCP)		Without soaking (WPSCP)	
Iron (mg/kg)	Beans	Broth	Beans	Broth	Beans	Broth	Beans	Broth
BRS Vereda	48.4 (±3.1)[c]	24.8 (±3.1)[c]	56.8 (±0.8)	13.2 (±0.8)	51.5 (±2.5)[a]	17.3 (±2.5)[a]	56.4 (±4.5)[b,d]	12.4 (±6.4)[b]
BRS Grafite	49.5 (±0.5)[c]	19.9 (±0.5)[c]	54.0 (±0.7)	15.5 (±0.7)	60.9 (±3.4)[a]	8.5 (±3.4)[a]	61.9 (±2.0)[b]	7.6 (±2.0)[b]
BRS Radiante	42.8 (±0.9)[c]	10.3 (±0.9)[c]	51.3 (±0.1)	1.8 (±0.1)	39.2 (±1.7)[a]	13.9 (±1.7)[a]	41.6 (±2.5)[b]	11.5 (±2.5)[b]
BRS Pontal	54.9 (±2.3)	7.4 (±2.3)	54.0 (±0.2)	8.3 (±0.2)	50.6 (±2.7)	11.7 (±2.7)	55.3 (±1.7)[d]	6.9 (±1.7)
BRS Marfim	49.6 (±0.3)[c]	33.6 (±0.3)[c]	47.4 (±0.7)	36.2 (±0.7)	74.4 (±0.4)[a]	0.9 (±0.4)[a]	70.4 (±0.4)[b,d]	4.4 (±0.4)[b]
Jalo Precoce	41.2 (±3.1)[c]	15.4 (±3.1)[c]	46.9 (±4.3)	9.6 (±4.3)	38.0 (±2.0)	18.6 (±2.0)	50.5 (±0.1)[b,d]	6.1 (±0.1)[b]

Mean and standard deviation: 1 – dry basis results.
SPP, with previous soaking in water and pressure cooked; WSPP, without soaking in water and pressure cooked; SCP, with previous soaking in water and cooked in a regular pot; WPSCP, without previous soaking in water and cooked in a regular pot.
[a]Significantly different from SPP.
[b]Significantly different from WSPP.
[c]Significantly different from WSPP.
[d]Significantly different from WPSCP (unpaired *t* test).

and broth together, the total zinc contents were 42.7 (BRS Pontal) and 43.1 mg/kg, respectively.

Table 4 shows the zinc contents in cooked grain and in the broth of common bean cultivars after different cooking methods, with no significant differences being found between the two types of cooking (regular pot and pressure cooker). However, previous soaking in water was found to influence the zinc contents in the cooked grains of the cultivars BRS Grafite, BRS Radiante, and BRS Pontal.

Discussion

According to Coelho et al. (16), cooking time depends mainly on the cultivar studied and the soaking time. They found different results in cooking times with the BRS Valente cultivar previously soaked in deionized water for 6 h (23–30 min) in contrast to our results which showed that cooking times after soaking varied from 13.81 (BRS Grafite) to 19.75 min (BRS Radiante).

The cultivars analyzed presented iron contents ranging from 74.7 (BRS Marfim) to 53.1 mg/kg (BRS Radiante). However, the cultivars analyzed presented zinc contents ranging from 33.8 mg/kg (Jalo Precoce) to 43.1 mg/kg (BRS Grafite), which are higher than those found in a study by Ribeiro et al. (17), who demonstrated iron contents of 71.54 mg/kg and zinc of 30.05 mg/kg as well as by Beebe et al. (18) in bean cultivars grown in Colombia.

The tendency toward higher zinc content in cooked beans may be due to the fact that soaking is more effective in increasing the extractability of trace elements like copper, zinc, and manganese, while fermenta-

Table 4. Zinc content (mg/Kg dry matter) in cooked beans and bean broth

	Pressure cooking				Regular pot			
	With soaking (SPP)		Without soaking (WSPP)		With soaking (SCP)		Without soaking (WPSCP)	
Zinco (mg/kg)	beans	Broth	beans	broth	beans	broth	beans	Broth
BRS Vereda	30.9 (±0.3)	8.4 (±0.3)	30.6 (±2.3)	8.8 (±2.3)	28.4 (±1.4)	9.8 (±1.4)	29.8 (±1.3)	9.6 (±1.3)
BRS Grafite	36.1 (±1.2)	6.9 (±1.2)	38.8 (±0.3)	4.3 (±0.3)[a]	34.4 (±1.1)	8.7 (±1.1)	38.5 (±0.9)	4.6 (±0.9)[b]
BRS Radiante	25.3 (±0.8)	8.2 (±0.8)	32.8 (±0.3)	0.8 (±0.3)[a]	28.1 (±2.6)	5.4 (±2.6)	26.2 (±2.0)	7.4 (±2.0)[b]
BRS Pontal	26.6 (±1.9)	16.1 (±1.9)	32.7 (±0.6)	9.9 (±0.6)[a]	36.2(±1.2)	6.5 (±1.2)	31.8 (±0.9)	10.9 (±0.9)[b]
BRS Marfim	31.8 (±0.1)	7.9 (±0.1)	37.5 (±0.1)	2.6 (±0.1)	30.8 (±0.5)	9.8 (±0.5)	37.7 (±0.2)	2.7 (±0.2)
Jalo Precoce	26.5 (±2.5)	7.3 (±2.5)	27.2 (±2.0)	6.6 (±2.0)	27.9 (±0.6)	5.9 (±0.6)	27.6 (±2.2)	6.2 (±2.2)

Mean and standard deviation. [a]Significantly different from SPP; [b]significantly different from WPSCP (– unpaired *t* test). SPP – with previous immersion in water and pressure cooked; WSPP – without immersion in water and pressure cooked; SCP – with previous immersion in water and cooked in a regular pot; WPSCP – without previous immersion in water and cooked in a regular pot.

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tion can be more effective in increasing the iron extractability (19).

The values reported in the Brazilian Food Composition Table for iron and zinc in *Phaseolus vulgaris* ranged from 11 to 19 mg/kg, and 7 to 13 mg/kg in cooked samples, respectively. However, values are significantly higher in raw bean samples varying from 51 to 186 mg/kg for iron and 26 to 40 mg/kg, for zinc (20). It must be emphasized that in the results reported by Ramirez-Cárdenas et al. (21) the grain values and the bean broth analyzed were considered as a single sample.

A food can be labeled as the 'source' of a nutrient when 100 g of the product presents more than 15% of the dietary reference intake (DRI) for the desired nutrient. For example, 15% DRI is equivalent to 21 mg/Kg of the product (2.1 mg/100 g) and zinc 22.5 mg/Kg (2.25 mg/100 g) is considered as a source, and contains 42 μg of iron/g of the product and 45 mg/Kg for zinc when considered high. Similarly, when the food contains at least double the amount determined as a 'source', it can be labeled 'high'. The DRI value recommended for iron is 14 mg/day and for zinc 15 mg/day (22).

In view of the iron and zinc deficiencies and high values found in some of the cultivars analyzed by Mechi et al. (23), black common bean cultivation and consumption can be indicated to meet these deficiencies in low-income populations of underdeveloped and developing countries, mainly in infants and pregnant women.

Overall, regardless of the type of home cooking method, with or without water soaking, the highest zinc concentration was found in the cooked bean grain (BRS Grafite with and without previous soaking cooked under pressure). However, pressure cooking and previous water soaking influenced iron and zinc retention in the cooked bean grain, complementing the concentration of this nutrient in the bean broth.

According to Mechi et al. (23) iron contents ranging from 98 to 126.3 mg/kg were found in black beans (*P. vulgaris* L.) raw and cooked, respectively (in dry basis). The USDA reported contents of 56.42 and 61.30 mg/kg for raw and cooked beans, respectively (24). However, another value was reported by FAO (93 mg/kg) in raw black beans (25).

Thus, the common bean was confirmed to be an excellent source of iron and zinc for human consumption since phytic acid is reduced after processes such as soaking, germination, and heat, promoting an increase in mineral extractability and bioavailability. The presence of phytates and tannins in vegetable fibers can negatively influence the bioavailability of zinc and iron as well as the cooking of the grain. However, the tannins have no significant influence on the bioavailability of zinc and iron from cereals and legumes (26).

Considering that the majority of the population is iron deficient worldwide, the high content found in the studied cultivars, mainly in BRS Pontal, confirms the fact that the common bean can be considered a good source of iron as well as of zinc, and help fight anemia in low-income populations of underdeveloped and developing countries, especially in infants and pregnant women.

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Conflict of interest and funding

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